US Army Corps
of Engineers ®
Portland District

# Tillamook Bay and Estuary, Oregon
# General Investigation Feasibility Report

# APPENDIX A

# Overview of Hydrologic Study and Model Development

Prepared by
U.S. Army Corps of Engineers
Portland District
CENWP-EC-HY

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# APPENDIX A
# Overview of Hydrologic Study and Model Development

## TABLE OF CONTENTS

# Table of Contents (continued)



**LIST OF TABLES**



**LIST OF FIGURES**

# Table of Contents (continued)

**LIST OF FIGURES (continued)**

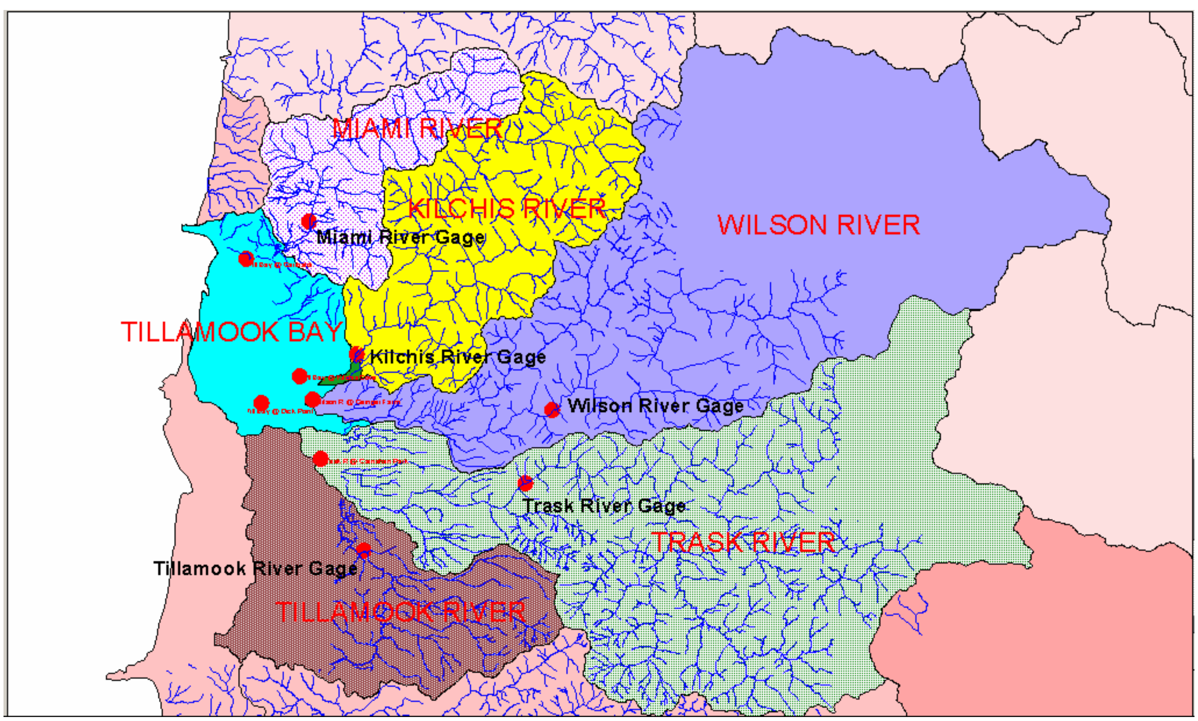
## INTRODUCTION

Like many rivers along the northwest Oregon Coast, the rivers of Tillamook Bay represent a complex ecosystem of multiple channels exiting into a shallow bay. This General Investigation feasibility study involved studying the five rivers of Tillamook Bay as well as the bay itself to determine the nature of flooding and changes that have occurred over time that have altered the natural regime of ebb and flood in the area. Tillamook is a shallow bay with an average depth of 5.9 feet and an average tidal range of 5.6 feet. During ebb tide the bay becomes a virtual mudflat. The bay enters the Pacific Ocean through a single channel that has been modified by jetties and dredging at its northern end for navigation purposes.

The watershed surrounding Tillamook Bay is dominated by broad valleys along the coastal plain that abruptly rise to steep mountains of the Coast Range. Elevations vary from near sea level in the coastal lowlands to above 3,500 feet in the Coast Range. The majority of area of each watershed contributing to the bay is located within the coastal mountains. Dense forest covers much of the terrain, which overlies impermeable strata in the mountainous watershed. The majority of human settlement has taken place in the broad river valleys. The valley forests were stripped, wetlands were filled and levees were placed in the valleys for agricultural purposes around 150 years ago.

Tillamook Bay has five principle rivers – the Wilson, Trask, Tillamook, Kilchis, and Miami. The Wilson and Trask Rivers are the two largest rivers in the area and contribute to the majority of sedimentation and flooding in the bay. The Miami and Kilchis Rivers have similar watersheds and characteristics as the Wilson and Trask, but they are smaller and are located in sparsely populated areas. The Tillamook River is the odd river of the five with a low gradient relative to the other rivers and a watershed located along the coastal foothills. The Tillamook River contributes the least to flooding and erosion problems in the region. Four of the five rivers are concentrated at the southern end of the bay, while the Miami River flows into its northern end (Figure 1).

*Figure 1. Five Watersheds of Tillamook Bay*



The majority of settlement in the area occurred in and around the community of Tillamook. The City of Tillamook was founded in 1852 along a low-ridge separating the Trask and Wilson Rivers. The surrounding floodplains of the Tillamook, Trask and Wilson Rivers were developed for agriculture. As the area is rich in rainfall, grasses are plentiful and the Tillamook area has long been an excellent location for dairy products. Beyond the city lie numerous dairies throughout each of the five major river valleys.

For purposes of agriculture, the floodplains of the rivers have been diked, sloughs have been filled, and structures have restricted the historic movement of the river channels. In essence ties of floodplain to river channel have been separated in the river valleys of the area. A few major sloughs remain connected to their rivers including the Dougherty Slough to the Wilson River and Squeedunk Slough to the Kilchis River. Other sloughs in the area have generally lost their upstream tie to rivers and now are either stagnant or tidal sloughs.

The original boundary of this study included Tillamook Bay and its entire watershed. Upon evaluation of the area and discussions with the Oregon Department of Forestry (ODF), it became apparent that the upland forests could not be studied. First, it was too large of an area to perform any detailed analysis and secondly, ODF was not interested in participating as it was their contention that impetus for the study did not coincide with their interests. Furthermore, the original scope of work for this study included a hydrologic modeling effort of the watersheds of Tillamook Bay. However, ODF did not support the use of hydrologic models. It was determined that the majority of issues concerning flooding, salmon habitat, water quality, and sedimentation were focused on the developed floodplains on each of the five rivers. Therefore, the study was scoped based on evaluating the areas that include the lowland river valleys and coastal floodplains to Tillamook Bay.

Prior to this study, the most recent hydraulic modeling study of the Tillamook area was performed in late 1960s and early 1970s by the Corps and CH2M Hill in development of the Federal Emergency Management Agency’s (FEMA) Flood Insurance Report for Tillamook County. This modeling utilized 2-foot topographic data and cross-sectional data gathered in 1965. The study evaluated the rivers with the one-dimensional, steady-state model HEC-2. As all the rivers of Tillamook Bay are tidally influenced, it was readily apparent that the only way to develop a good understanding of flood behavior in the area was to develop an unsteady flow model of the rivers of Tillamook Bay.

Initial scoping efforts for the study included the development of the Corps’ one-dimensional, unsteady flow model UNET. However, during the scoping phase of the study, the Danish Hydraulic Institute was in the region promoting their unsteady flow model MIKE11. At the time, their model boasted the ability to create flood area maps and ‘slideshows.’ Also, their model was integrated in a system that allowed the user to incorporate multiple modeling modules such as sedimentation, water quality, and hydrologic models. The study sponsor, Tillamook County, was sold on the benefits of viewing flooded areas with the MIKE11 model. Therefore, it was initially decided to use the Danish Hydraulic Institute’s MIKE11 model for this feasibility study.

However, later in the study a decision was made to convert the existing MIKE11 model to the Corps’ HEC-RAS model. At the time the MIKE11 model was selected for use, it had a solid reputation, whereas not enough information was available for the HEC-RAS model. Since then, a newer version of the HEC-RAS model was developed, which is more sophisticated than MIKE11 and more capable of addressing the complex nature of flooding in the Tillamook area. The HEC-RAS is currently the most common river analysis model used. The HEC-RAS model will be able to serve the Tillamook study area in an easier and less expensive manner. WEST Consultants Inc., under contract by the Corps, performed the conversion of the MIKE11 model to HEC-RAS.

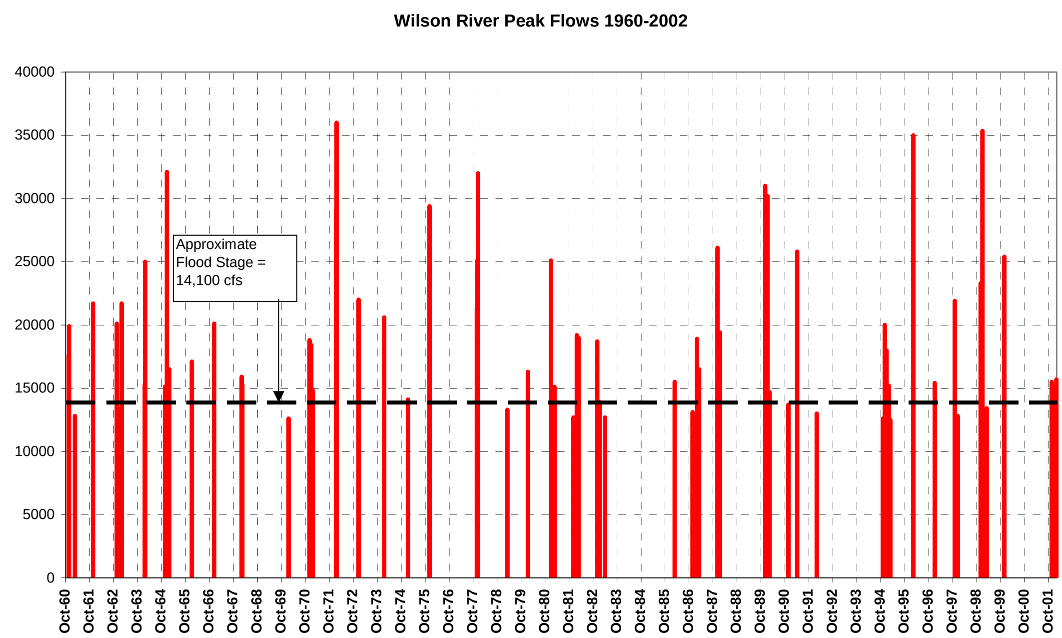
## FLOODING IN THE TILLAMOOK REGION

Much of the impetus for this study lies in the flooding that has occurred in the valleys of the Tillamook Bay region, with the most severe flooding occurring in and around the City of Tillamook. The floods of February 1996 were region-wide and were especially devastating in the area. Flooding in the region occurs on a regular basis. The city lies along a ridge that separates the Wilson and the Trask Rivers. Just downstream of the City is Tillamook Bay. The Wilson and Trask Rivers are the two largest Rivers flowing into the bay; in turn, they produce the largest floods. The city itself largely remains flood free; however, newly developed areas to the north and south of the city experience flooding on a regular basis. The worst flooding occurs to the north of the city along Highway 101. This recently developed area lies in the direct path of floodwaters from the Wilson River. With elevations as low as 9 feet MLLW on Highway 101, it is apparent why flooding is so devastating to this area. Flood waters come from all sides, from the Wilson River, the Trask River, the Tillamook River, and from high tides and storm surges in Tillamook Bay. Other areas of Tillamook including along the Trask, Tillamook and Kilchis Rivers have been historically flooded as well.

The majority of lands in the area are operated as dairy farms and many of the historic dairies are located on high points throughout the area. Many dikes have been built around the area; however, only the Stillwell levee actually protects a large tract of land from being flooded. The Stillwell Levee was completed by the Corps in 1960 and protects a large farmed area that lies at the mouth of the Trask and Tillamook Rivers. The levee forces waters to flow around it through two narrow channels – the Trask and Tillamook Rivers. Floodwaters regularly overtop their banks upstream of the Stillwell levee and flood the area between the Trask and Tillamook Rivers as a result.

Lying between the Pacific Ocean and one of the wettest coastal mountain ranges in North America, the lowlands of Tillamook have always flooded and will continue to flood. As shown in Figure 2, the Wilson River has reached flood stage (approximately 14,100 cfs) numerous times over the past 32 years. In fact, the Wilson has exceeded flood stage approximately 60 times, averaging to almost two floods per year in the recent past.

*Figure 2. Peaks for Recent Floods on the Wilson River (in cfs)*



## TILLAMOOK AREA HYDROLOGY

The Tillamook area is hydrologically active. Located on the Northwest Coast of the United States, Tillamook lies in the direct path of the north pacific jet stream. Storms come off the Pacific Ocean and encounter the Coast Range immediately east of the coast. As the storms rise over the coastal mountains, they release significant amounts of precipitation. With locations at the top of the Coast Range receiving over 200 inches of precipitation per year, this is one of the wettest locations in North America. Most of the precipitation falls as rain and most falls between the months of October and March. Locations in the lowland valleys receive significant rainfall as well, averaging approximately 100-inches per year. With all the rainfall come large amounts of runoff. It is fairly normal for the Wilson River to rise 10,000 cfs in a matter of hours during winter storm events.

The Tillamook region has very few long-term precipitation gauges. A precipitation gauge at the local radio station has been in operation since 1948, and another gauge near the Nehalem River has been operated since 1948. Other precipitation gauges have been in operation on a sporadic basis. Stream gauges also have been operated on a sporadic basis.

### Discharge-frequency Relationships

*Wilson River*

The Wilson River has a drainage area of 161 square miles at its gauged location an additional 30 square miles of area joins the Wilson River on its way to Tillamook Bay. Therefore, approximately 84% of the drainage area is gauged. The North Fork of the Wilson River enters the Wilson River at river mile (RM) 8.61 and represents approximately 66% of the remaining 30 square miles of ungauged tributary area.

Using the Corps' HEC-FFA (flood flow frequency model), the following discharge-frequency relationship was computed for the Wilson River (Figure 3). The frequency curve contains 71 years of peak flood values ranging from a peak value of 36,000 cfs in 1972 to 3,665 cfs in 2001. Utilizing current Corps' regulations, values used for this study rely on expected probability of occurrence.

Historic computations of discharge-frequency on the Wilson River include the U.S. Geological Survey (USGS) report of 1993 documenting statistical summaries of gauges in Oregon. Other historic computations include the Tillamook County FEMA Flood Insurance Study of 1978 that was recently updated for the lower Wilson River in 2000. Table 1 summarizes peak discharge values from the two historic studies in comparison with this study.

*Table 1. Wilson River near Tillamook, Oregon - Annual Peak Discharge-frequency Values from Historic Studies*

| Study/Date | Discharge in cfs for Indicated Annual Percent Chance of Exceedance | | | | |
|---|---|---|---|---|---|
| | **50%** | **10%** | **2%** | **1%** | **0.2%** |
| Corps/2002<br>p.o.r. 1932-2002 | 17,700 | 27,800 | 36,100 | 39,400 | 47,200 |
| USGS/1993<br>p.o.r. 1915-1987 | 17,200 | 26,300 | 33,100 | 35,800 | NA |
| FEMA (CH2M Hill)/1978<br>p.o.r. 1932-1976 | NA | 25,000 | 33,000 | 36,300 | 43,500 |

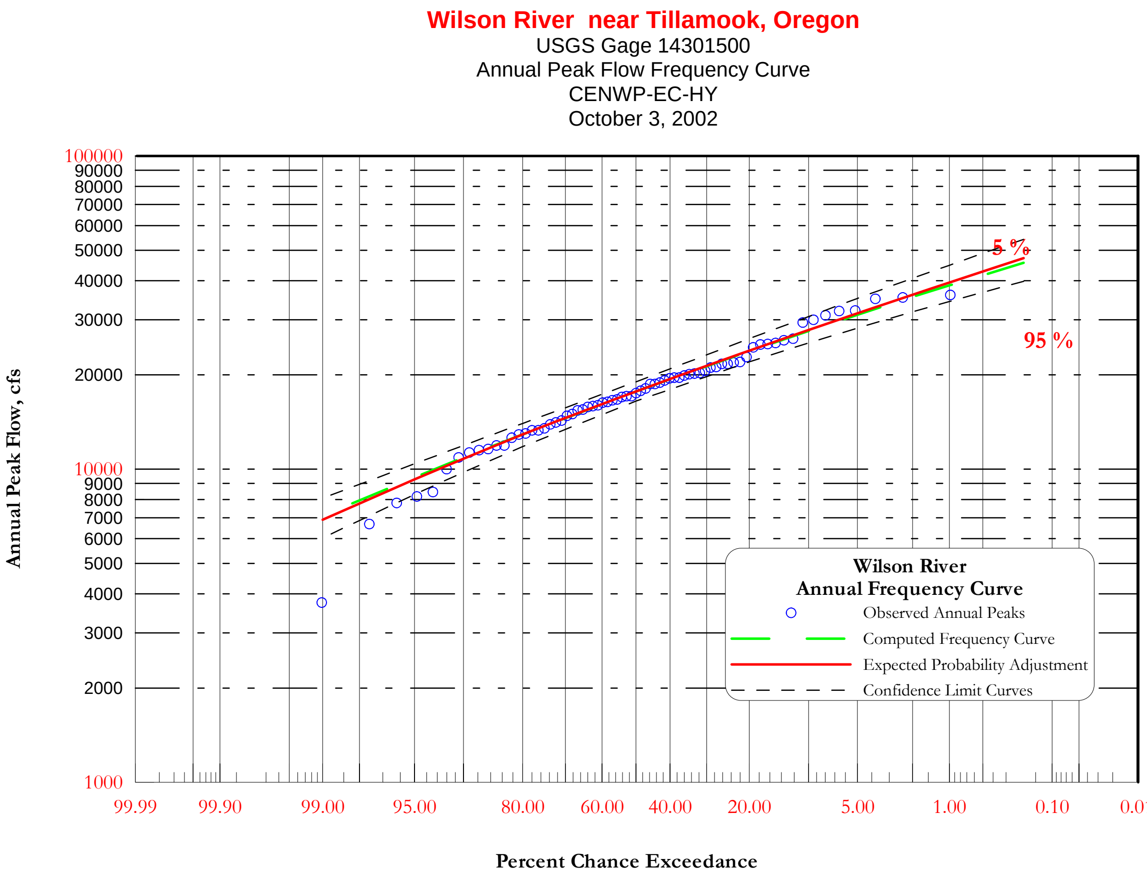


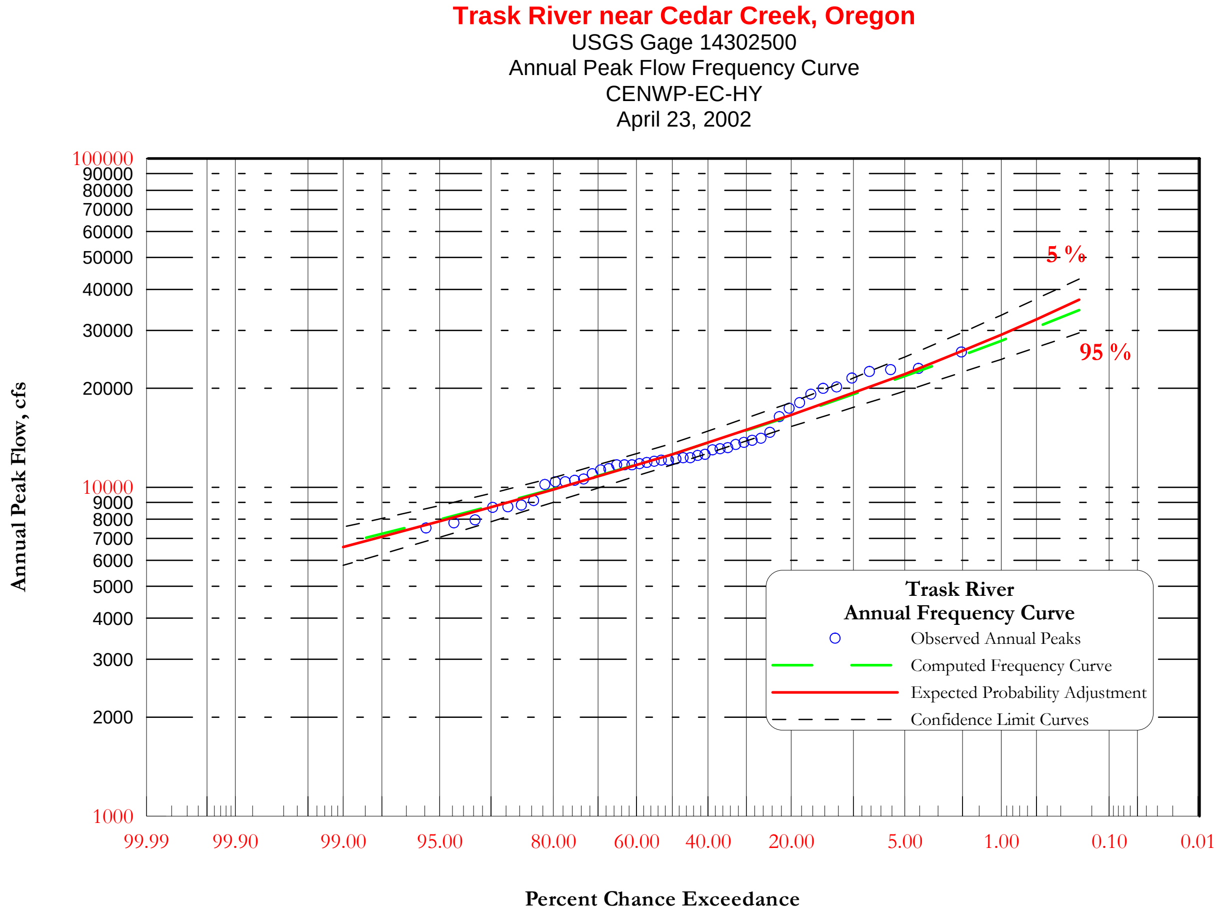

*Figure 3. Wilson River near Tillamook, Oregon Peak Discharge-frequency Relationship*

## *Trask River*

The Trask River has a drainage area of 145 square miles at its gauged location with an additional 14 square miles of area that joins the Trask River on its way to Tillamook Bay. Therefore, approximately 91% of the drainage area is gauged. No major tributaries enter the Trask River below the gauge, only minor tributaries.

Using the Corps' program HEC-FFA, the following discharge-frequency relationship was computed for the Trask River (Figure 4). The frequency curve contains 48 years of peak flood values ranging from a peak value of 25,800 cfs in 1996 (est.) to 2,520 cfs in 2001.

*Figure 4. Trask River near Cedar Creek, Oregon Peak Discharge-frequency Relationship*




Historic computations of discharge-frequency on the Trask River include the USGS Report of 1993 documenting statistical summaries of gauges in Oregon. Other historic computations include the 1978 Tillamook County FEMA Flood Insurance Study. Table 2 summarizes peak discharge values from the two historic studies in comparison with this study.

*Table 2. Trask River near Cedar Creek, Oregon - Annual Peak Discharge-frequency Values from Historic Studies*

| **Study/Date** | **Discharge in cfs for Indicated Annual Percent Chance of Exceedance** | | | | |
|---|---|---|---|---|---|
| | **50%** | **10%** | **2%** | **1%** | **0.2%** |
| USACE/2002<br>p.o.r. 1932-1972, 1996-2002 | 12,600 | 19,400 | 26,000 | 29,100 | 37,200 |
| USGS/1993<br>p.o.r. 1922-1972 | 12,600 | 19,300 | 25,800 | 28,800 | NA |
| FEMA (CH2M Hill)/1978<br>p.o.r. 1932-1972 | NA | 19,000 | 24,700 | 27,400 | 33,100 |

*Tillamook River*

The Tillamook River has a drainage area of approximately 60 square miles at its downstream terminus into Tillamook Bay. The watershed of the Tillamook River differs from the other four major rivers of the bay in that its origins arise in the lowland coastal foothills and valleys paralleling the coast rather than from the steep Coast Range. Therefore, orographic effects on the watershed are less pronounced than the other four rivers resulting in a lower flood peak to drainage area ratio. Also, there is much less historic hydrologic data for the watershed than other watersheds in the region. The river has had a few periods of gauging including 1973-1977, 1995-1998, and February 2001 to the present. All gauging has been performed by the Oregon Water Resources Department (OWRD) and the latter period of gauging was funded for this feasibility study. With only 8 years of non-continuous record, it is difficult to produce a discharge-frequency curve for this river for any event larger than possibly a 10% chance of exceedance. Table 3 shows the Tillamook River discharge-frequency values from the 1978 FEMA Flood Insurance Study of Tillamook County. These values are based on the USGS Regional flood frequency method. Further analysis was not performed for this river during this feasibility study.

An estimate of the flow for the Tillamook November 1999 flood event was required since no data was recorded on the Tillamook River during this time. Comparisons were made between the peak flows on the Wilson, Trask, and Tillamook Rivers when they occurred for the same event between November 1995 and November 1998 (see Appendix B, *Hydraulic Modeling for the Tillamook Bay and Estuary Study*, prepared by WEST Consultants, Inc.). The Tillamook River was approximated as 18% of the Wilson River flow for the November 1999 event based on this analysis.

*Table 3. Tillamook River at Old Trask Confluence - Annual Peak Discharge-frequency values from 1978 FEMA Study*

| **Study/Date** | **Discharge in cfs for Indicated Annual Percent Chance of Exceedance** | | | | |
|---|---|---|---|---|---|
| | **50%** | **10%** | **2%** | **1%** | **0.2%** |
| FEMA (CH2M Hill)/1978 | NA | 7,170 | 9,730 | 10,800 | 13,400 |

*Kilchis River*

The Kilchis River has a drainage area of approximately 67.3 square miles at its terminus in Tillamook Bay. The watershed of the Kilchis River is similar to that of the Wilson River in that it is dominated by the Coast Range, which is steep forested terrain with shallow soils over impermeable strata. Orographic characteristics of the watershed lead to steep hydrographs with relatively large peak flows during winter rain events. Little gauging has been performed on this river. The OWRD began gauging the river in 1995 and continued this gauge until 1998, whereupon funding was cut and the gauge became idle. At the onset of this feasibility study, it was apparent that better streamflow data would be necessary to model this river. Therefore, the OWRD was funded to continue gauging on the Kilchis River. Gauging began in the spring of 2001 and continued for 2 years until the spring of 2003. The intention of the additional gauging was to capture large storm events to analyze the watershed's response to those events and utilize the information as a boundary condition in the hydrodynamic model. With only 4 years of gauging data, it is difficult to develop statistical relationships for this river beyond the 10%-50% chance of exceedance. The flood of 1996 approximately represented a 2% chance of exceedance event on the Wilson River, and the peak flow on the Kilchis River for this event was approximately 15,971 cfs. Based on the inherent locations and geology of the two watersheds, it was assumed that they behave very similarly. Also, looking at the estimates of discharge-frequency from the 1978 FEMA Flood Insurance Study, their estimate of 13,895 cfs for the 50-year event on this river is approximately 14% less than the peak of 1996, while the Wilson peak from their estimate (35,000 versus 33,000 cfs) also was underestimated. Therefore, it was assumed that 16,000 cfs approximately represents the 2% chance of exceedance for the Kilchis River. From this preliminary analysis, it appeared that the expected probability of the Wilson and Kilchis Rivers are linearly related; Table 4 shows the resulting exceedance probability statistics as compared to the 1978 FEMA study.

*Table 4. Kilchis River near Tillamook, Oregon - Annual Peak Discharge-frequency Values from Historic Studies*

| Study/Date | Discharge in cfs for Indicated Annual Percent Chance of Exceedance | | | | |
|---|---|---|---|---|---|
| | **50%** | **10%** | **2%** | **1%** | **0.2%** |
| USACE/2002<br>(based on 0.457*Wilson Peak) | 8,100 | 12,700 | 16,500 | 18,000 | 21,600 |
| FEMA (CH2M Hill)/1978<br>(estimated) | NA | 10,240 | 13,895 | 15,360 | 18,965 |

*Miami River*

The Miami River has a drainage area of 36.4 square miles at its terminus with Tillamook Bay. Much like the Kilchis, Wilson, and Trask Rivers to the south, the Miami has its origins in the mountainous Coast Range and responds quickly to intense precipitation and often producing steep hydrographs with significant peak flows relative to the size of its watershed. The Miami River has been gauged near Moss Creek by the OWRD intermittently since 1975. Although a significant amount of gauge data exists, the Corps was only able to obtain data from the OWRD for the years 1995-1998 and 1999-2002. With only 7 years of data, it was difficult to develop sufficient discharge-frequency relationships beyond the 10-year event. During the period 1995-2002, the largest event occurred on February 7, 1996 with a recorded flow of approximately 9,900 cfs. However, this reading is suspect because the gauge was washed out during this flood. Other large floods of note during the period include the November 1999 flood where the gauge recorded a peak flow of approximately 5,600 cfs. Another large flow of 6,200 cfs occurred in November 1995. Discharge-frequency curves were not developed for this gauge. Table 5 shows the Tillamook River discharge-frequency values (based on USGS regional methods) from the 1978 FEMA Flood Insurance Study.

*Table 5. Miami River at Mouth of Miami Cove – Annual Peak Discharge-frequency Values from 1978 FEMA Study*

| Study/Date | Discharge in cfs for Indicated Annual Percent Chance of Exceedance | | | | |
|---|---|---|---|---|---|
| | **50%** | **10%** | **2%** | **1%** | **0.2%** |
| FEMA (CH2M Hill)/1978 | NA | 5,650 | 7,220 | 7,900 | 9,400 |

**MIKE11 MODEL**

The MIKE11 model is a one-dimensional, unsteady flow model developed by the Danish Hydraulic Institute. The hydrodynamic model solves the Saint Venant equations for fluid momentum and continuity by a finite difference scheme utilizing an alternating grid. Thus, at each point in the model grid, the model solves for either stage (H) or flow (Q) on an alternating basis. The model also is able to solve general hydraulic equations for hydraulic structures as internal boundary conditions such as weirs and culverts. Basic input to the model includes river cross-sections, structural geometries and geographical networks. It utilizes branches to model rivers and floodplains that consist of nodes (points along the branch) with corresponding cross-sectional dimensions. As with all unsteady flow models, it requires a boundary condition at all upstream branches and downstream branches of a model network. In the case of Tillamook, flow gauges were utilized at all upstream ends of the five rivers and the downstream boundary consisted of tidal conditions in Tillamook Bay.

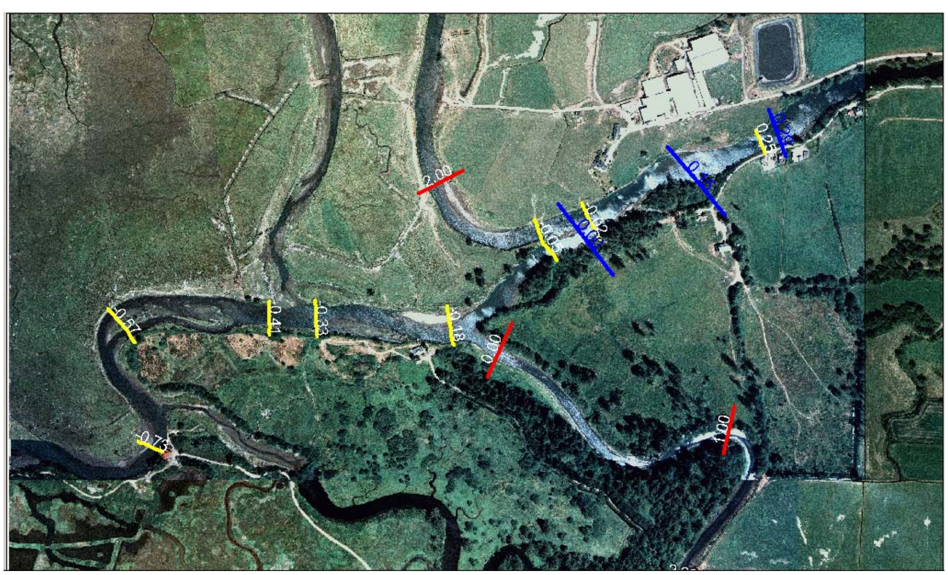
## Tillamook Area MIKE11 Model Overview

### *Geometric Data Collection*

<u>River Cross-sections</u>

The MIKE11 modeling of the rivers of Tillamook Bay for this feasibility study included a vast database of nearly 300 physical river cross-sections. Cross-sections for the base hydraulic model of the rivers in the Tillamook area were laid out initially in the summer of 1999 by the Corps. Cross-sections were laid out based on hydraulic properties of the channel including channel junctions, expansions and contractions. Cross-sections were laid out at approximately each 0.25-river mile along the Wilson, Trask, Old Trask, Tillamook, Kilchis and Miami Rivers, as well as several in Dougherty, Hall and Hoquarten Sloughs (Figure 5). Four sections were surveyed at all area bridges to account for bridge hydraulics. The vast majority of cross-sections were surveyed by the Tillamook County Surveyors Office in the summer and fall of 2000. Surveys were performed utilizing GPS techniques, which were later archived in a GIS database for visualization and spatial placement. A mapping study of the Lower Wilson River including Hoquarten and Dougherty Sloughs was performed by FEMA in 1999. Cross-sections from that study were used on Hoquarten Slough, Dougherty Slough and the Wilson River from RM 0.0 to approximately RM 5.0. Supplemental cross-sections were gathered by the Corps from 2000-2001 utilizing GPS techniques for several areas including Hall Slough, the Lower Wilson River, the Kilchis River and Dougherty Slough.

*Figure 5. Example of River Cross-sections at the Mouth of the Wilson River*



## Floodplain Mapping

The Corps performed floodplain mapping of the lower river floodplain areas to be modeled for this feasibility study. Floodplain mapping was performed utilizing aerial photogrammetric techniques. Aerial photographs of the area were made in September 1999 with some re-flight of the lower Wilson, Tillamook and Trask Rivers in March 2000. Mapping of the resulting aerial photographs was performed to a two-foot contour level of accuracy (accurate to ± 1 foot.) From the ortho-rectified mapping, three-dimensional points were extracted. Three-dimensional (x-y-z) points formed the backbone of the mapping. Within a Geographical Information System (GIS) the three-dimensional points were triangulated. Triangulation of the three-dimensional points resulted in a triangulated irregular network (TIN) of the floodplain areas to be modeled. The resulting TINs were utilized for cutting of floodplain cross-sections, measuring of volumes, mapping contours, and visualizing flooded areas. Figure 6 shows the process used to create floodplain mapping for this study.

## River Structures

River structures for this study include bridges, culverts, levees and tidegates. Bridges were surveyed by the Tillamook County Surveyors office (river cross-sections) and by the Corps. Generally, four cross-sections were obtained at each bridge: one upstream of the bridge at the river’s unobstructed contraction point; one at the upstream face of the bridge; one at the downstream face of the bridge; and one located downstream of the bridge at the river’s fully expanded flow point. Other information about each bridge including its hydraulic properties was obtained by the Corps from field survey, photographs, and previous studies.

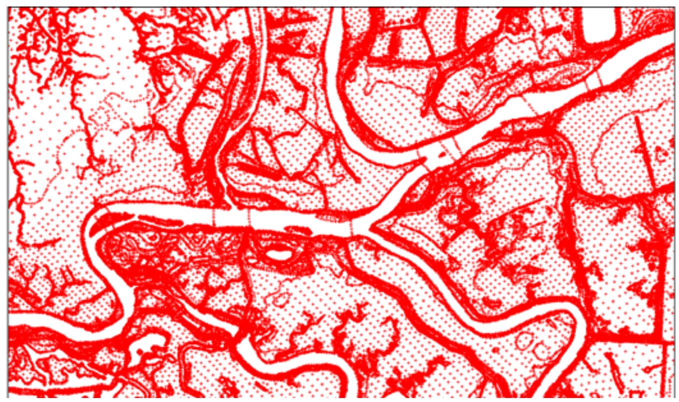
Because all area rivers are tidally influenced, there are many tidal dikes in the region to control tide waters from inundating the floodplain. Dike dimensions including elevations were derived from the floodplain mapping TINs previously discussed. This methodology was acceptable in most instances. However, several dikes had thick vegetation on and/or around them. In these locations, aerial mapping was not accurate. Several tidal dikes appeared to flood in normal tidal conditions. Dikes were raised to a reasonable level based on local channel cross-section information and tidal heights.

Interior drainage in the Tillamook region is provided by hundreds of tide-gated culverts throughout the lower river system. Because there are so many private culverts, it was impossible to survey them all for this study. The Tillamook County Watershed Council in cooperation with the National Estuary Project at Tillamook Bay had recently completed a cursory inventory of all the culverts of the area. Data for each culvert included their size and if the culvert was tide-gated or open. This data was used to develop the initial models. Other necessary data for each culvert included its elevation, length, Manning’s roughness and entrance properties. Some culvert lengths were listed in the Tillamook County report, while others were estimated based on the floodplain mapping. Most elevations of culverts were estimated from floodplain mapping. In some instances, culvert data was too important to estimate. At those locations, a local contractor (Nehalem Marine) was hired to survey approximately 20 culverts. Other data was gathered from Nehalem Marine’s records of recent culvert replacement and installations.

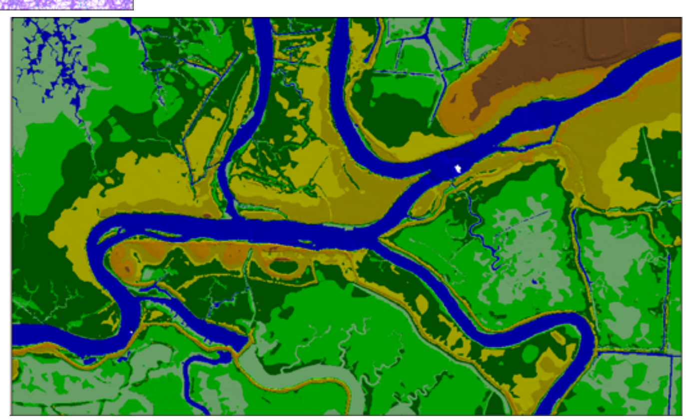
*Figure 6. Diagram of Floodplain Mapping for Tillamook, Oregon*

**From the aerial photography, three-dimensional points were extracted.**

**From the three-dimensional points, a TIN was created.**



**From the TIN, a three-dimensional picture of the floodplain was created.**



*Boundary Condition Data Collection*

Boundary data refers to hydrologic data that is necessary throughout the hydraulic model at each point within the model that is either an end to a reach, a beginning of a reach or a source or sink of water within a reach. For each major river in the study area, a boundary condition was necessary at the upstream end of the river and at the downstream end of the river. For the major rivers in the Tillamook models, stream flows were used as upstream boundaries and tidal elevations of Tillamook Bay were used as downstream conditions. Boundary conditions were estimated based on existing gauge data as well as gauges installed specifically for this study. Tables 6 and 7 show the existing and historic stream and tide gauges in the Tillamook region.

*Table 6. Historic Stream Gauges in the Tillamook Region*

| Stream | River Mile | Period of Record | Agency | Parameters |
|---|---|---|---|---|
| Miami River | 1.7 | 1975-2003 | OWRD | h, Q, temp |
| Kilchis River | 3.0 | 1995-1998, 2000-2002 | OWRD | h, Q, temp, WQ |
| Wilson River | 11.5 | 1931-2003 | USGS | h, Q |
| Trask River | 11.0 | 1932-1956, 1962-1972 | USGS | h, Q |
| Trask River | 10.95 | 1996-2003 | USGS | h, Q |
| Tillamook River | 6.90 | 1973-1977, 1995-1998, 2000-2002 | OWRD | h, Q, temp |
| Killam Creek | 2.1 | 1975-2002 | OWRD | h, Q |

Note: h = gauge height, Q = discharge, temp = water temperature, WQ = water quality (parameters vary)

*Table 7. Historic Tide Gauges in the Tillamook Region*

| Location | Period of Record | Agency | Parameters |
|---|---|---|---|
| Astoria | 1925-Present | NOAA/NOS | h |
| Garibaldi | 1970-1981 | NOAA/NOS | h |
| Yaquina | 1967-2004 | NOAA/NOS | h |
| North Jetty | 1970 | Corps | h |
| Kincheloe Point | 1970 | Corps | h |
| Bay City | 1970 | Corps | h |
| Dick Point | 1970 | Corps | h |

Note: h = gauge height; NOS = National Ocean Service

The USGS stream gauge on the Wilson River, which has been in operation for over 72 years, has the longest period of record of all the gauges in the Tillamook region. Another stream gauge in operation for many years is on the Trask River, also operated by the USGS. This gauge was removed in 1972 and replaced with a nearby gauge after the flood of 1996. Thus, many of the more recent large flood events were not captured on the Trask River, giving a less reliable flow-frequency relationship than that of the Wilson River. Stream gauges on the smaller rivers have been operated sporadically by the OWRD, except for the gauge on the Miami River which has been maintained for 28 years. Stream gauging on the Kilchis and Tillamook Rivers has been more sporadic. For the last 8 years, a gauging program was initially funded by the Tillamook Bay National Estuary Project on the Tillamook and Kilchis Rivers. Funding for these two gauges was exhausted in 1998; this study funded operation of those two gauges for the past 2 years of data collection.

Streamflow boundary conditions for upstream reaches were either used directly from these gauges for historic events or estimated from gauge data. Upstream boundary conditions for the MIKE11 model included the USGS gauges on the Wilson and Trask Rivers and the OWRD gauges on the Kilchis, Miami and Tillamook Rivers. Tillamook Bay is the downstream boundary for all five rivers in the study area. The Pacific Ocean controls the stages in Tillamook Bay with its jettied connection at its northern entrance. The only long-term record for Tillamook Bay stages was collected at Garibaldi between 1970 and 1981 by NOAA. During 1970, a physical modeling study was completed for Tillamook Bay by the Corps' Waterways Experiment Station (WES) that included placement of four tidal gauges in Tillamook Bay for model calibration. Gauges were placed at the North Jetty, Kincheloe Point, Bay City and Dick Point to determine tidal elevations throughout the bay.

Recent sedimentation in Tillamook Bay created an uncertainty as to tidal elevations throughout the bay. Therefore, a gauging program was established as part of this study. Purchase and placement of tidal gauges in Tillamook Bay was performed through cooperation between the Corps and Tillamook County. Gauges were placed at five locations throughout the bay during the spring of 2001. A fully automated (i.e. satellite telemeter) gauge was placed at Garibaldi at the U.S. Coast Guard boat house in March 2001. This gauge has been in operation since installation and records tidal stage in feet MLLW every 15 minutes. Data for this gauge is stored in the Corps' Columbia River Operational Hydrometerological System (CROHMS) database under the name 'TLBO.'

Recording gauges also were placed at various locations in Tillamook Bay for model boundary conditions and calibration (Table 8). This gauge data is physically downloaded and stored by the Corps. Gauges were located at or near river mouths to get a better understanding of tidal forcing conditions. All gauges measure tidal stage in feet using the North American Vertical Datum of 1988 (NAVD88) and water temperature every 15 minutes.

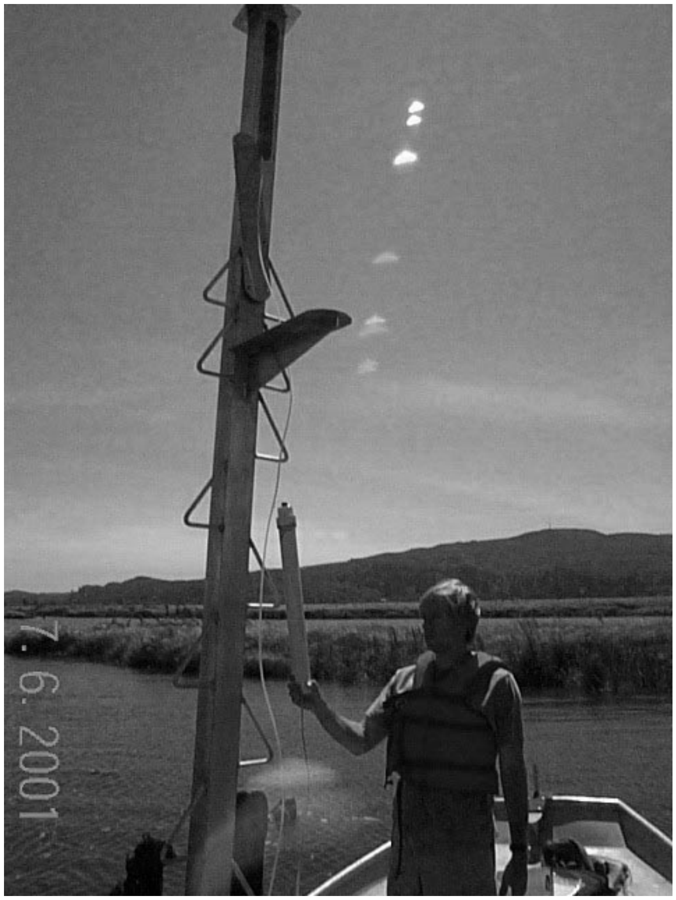
The Tillamook Bay at Garibaldi gauge was determined to be close enough to the mouth of the Miami River to not necessitate placing another gauge there. For the Kilchis River, a gauge was placed near the Kilchis River mouth at Kilchis Cove in April of 2001 (Figure 7). This gauge is a logging device that is located on a piling. The gauge is only accessible by boat. For the Wilson River, a logging gauge was placed in the river just before it splits into three branches at its mouth at approximately RM 0.30. This gauge is located on the right river bank on private property (Gienger Farms Inc.), which is leased by the Corps for gauging purposes. For the Trask River, a logging gauge was placed near its mouth at a boat dock at Carnahan Park near RM 1.2. The gauge is located on a pier of the boat dock and is accessible by car through the park. For the Tillamook River, a logging gauge was placed near its mouth in Tillamook Bay at Dick Point. The gauge is located on a pier at the same location as the gauge placed in 1970 in Tillamook Bay, and is only accessible by boat.

*Table 8. Stage-recording Gauges Installed by the Corps*

| Location | Period of Record | Parameters |
|---|---|---|
| Tillamook Bay at Dick Point | 2000-2003 | h, temp |
| Tillamook Bay at Garibaldi | 2000-2003 | h |
| Tillamook Bay at Kilchis Cove | 2000-2003 | h, temp |
| Wilson River at Gienger Farm | 2000-2003 | h, temp |
| Trask River at Carnahan Park | 2000-2003 | h, temp |

Note: h = gauge height, temp = water temperature

*Figure 7. Tide Gauge on the Kilchis River at Kilchis Cove*




Note logging device being held next to gauge housing.
Tidal range is approximately 10 feet at this location (Kilchis River at Kilchis Cove).

Figure 8 shows the tidal stage variation at the southern end of Tillamook Bay from data collected during the first four months of gauging. Note the variation of tidal prism from Dick Point to locations near the river mouths. Also, the Wilson River at Gienger Farm gauge shows a truncated tidal range in comparison to the other river gauges during ebb tide. This would indicate that a severe contraction occurs between the bay and the Gienger gauge. This contraction appears to be the result of sedimentation at the mouth of the Wilson River.

*Figure 8. Tidal Stages of Gauges at the Southern end of Tillamook Bay*


## *Calibration Data Collection*

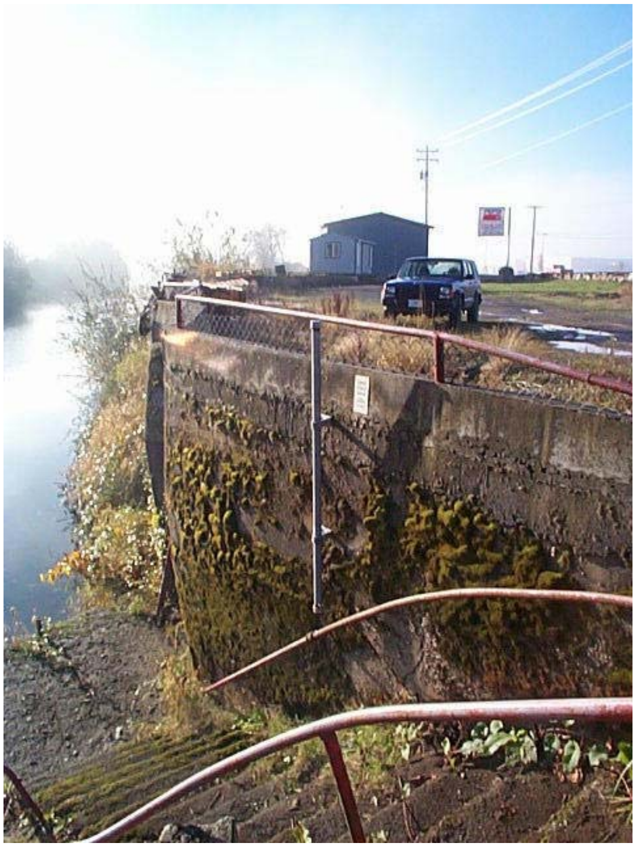
<u>Crest Stage Gauges</u>

Crest gauges consist of a pipe that is mounted to a fixed object in the floodplain at an elevation that is at the 'best-guess' for flood levels. Inside the pipe, a graduated rod rests along with ground cork that sets at the bottom of the pipe. Holes drilled into the bottom of the pipe allow floodwaters to fill the pipe. Cork floating on top of the water sticks to the rod as the flood recedes. After the flood, the rods are retrieved and read.

A network of crest stage gauges was placed in the region by the Corps at the onset of this study to obtain flood stage data to utilize in model calibration. Nineteen crest gauges were placed along Tillamook area rivers and sloughs in November 1999. Approximately 2 weeks later, the gauges were successful in capturing the maximum stages that occurred during the Thanksgiving flood. This data was utilized as the primary source of flood calibration for this study. Since this flood event, several other smaller events have occurred and have been documented from the crest gauge network. All floods captured (with the exception of the 1999 Thanksgiving flood) have been on the order of annual 2-year flood events.

Eighteen crest gauges were given to Tillamook County in the summer of 2001. These gauges were installed by the county throughout the Tillamook area to collect more flood-related stage data for this study and future management. Gauges were generally located on private properties with permission granted for inspection and data collection. A small flood event in January 2002 was captured by these gauges and was entered into the Corps' database.

*Figure 9. Crest Stage Gauge Located on the Lower Wilson River*



<u>Highwater Mark Surveys</u>

Other calibration data collected included the placement and survey of highwater marks. Approximately 50 highwater marks were placed by the Corps with noted time along all five rivers during an in-bank event on April 30 and May 1, 2001. The highwater marks were then surveyed on May 9-10, 2001. This data was used to develop a snapshot of water surface profiles of each river for known flow conditions to test the initial models for accuracy. On November 14-15, 2001, highwater marks also were placed and surveyed along the lower Wilson River and Highway 101 during a bank-full flood event to further calibrate the MIKE11 model for this area.

## *Tributary Inflows*

Tributaries within the modeling limits were added to the MIKE11 model as point source flow boundaries. Therefore, it was necessary to develop hydrographs for 26 tributaries. Tributary boundaries were delineated in a GIS system. Tributary areas were then calculated from the GIS database. Tributary flows were estimated individually based on their area compared to the area of the gauge that was used for estimation. Tributary flows were estimated based on drainage area ratio to that of the measured stream's hydrograph. Gauges used for tributary estimation included all five river gauges used for upstream boundary conditions. The specific gauge used was dependent on the model run. For some model runs, gauge data did not exist for each river. If gauge data did exist for that river, then generally the tributary flow was estimated from the gauge data for the river that it contributed to. It was determined that the tributaries did not contribute enough in the overall flow to make a difference for flood conditions. Therefore, if gauge data did not exist for the river, then other data was developed based on the individual model run.

The timing in the simulations of the local tributary inflow was assumed to be the same between the tributary inflow point to the river and the upstream boundary condition. Initial sensitivity tests indicated that the timing of the inflow did not significantly affect the overall water surface results. This is due in part to the magnitude of the small tributary inflows relative to the large, main river flows.

### *Model Boundaries*

The original study area, as defined in the Congressional Authority for the study, included Tillamook Bay and all the watershed area encompassing the bay. This vast area was too large to study in detail. Therefore, the 1999 reconnaissance study identified areas that were of greatest concern to the local community in terms of flooding problems and environmental concerns. Tillamook County requested that all five rivers of Tillamook Bay be modeled to the same extent. The area's rivers are all tidally influenced and are fed by the Coast Range Mountains. As the rivers flow from the Coast Range, their valleys widen and there slope decreases to create large coastal floodplains that have been utilized for agriculture for the past 150 years.

It became obvious that an unsteady model was necessary to analyze the hydraulics of the area and that the areas with the majority of flooding problems and environmental concerns were located in the coastal floodplains of each river. As unsteady flow models are only useful in areas with low slopes, it was determined that an unsteady flow model would be created for each of the five rivers within the coastal floodplain of each river. The Danish Hydraulic Institute's MIKE11 model was chosen for this study and this model was adapted to each of the rivers.

It was recognized that the Wilson, Trask, and Tillamook Rivers were all interconnected at their mouths; therefore, these three rivers would be modeled together. The Kilchis and Miami Rivers behaved independently and were modeled independently. It was determined that the Corps would coordinate all model development and obtain all necessary data for the modeling effort. The model for the Wilson, Trask, and Tillamook Rivers was contracted with WEST Consultants, Inc. The Corps developed the models for the Kilchis and Miami Rivers at the same time. Model boundaries included modeling from Tillamook Bay to RM 11.4 on the Wilson River, to RM 10.95 on the Trask River, to RM 6.90 on the Tillamook River, to RM 4.95 on the Miami River, and to RM 5.88 on the Kilchis River. Figures 10 to 12 show the model boundaries for the MIKE11 model.

*Figure 10. Area Encompassing the Wilson, Trask and Tillamook River MIKE11 Model (shown by dashed line)*

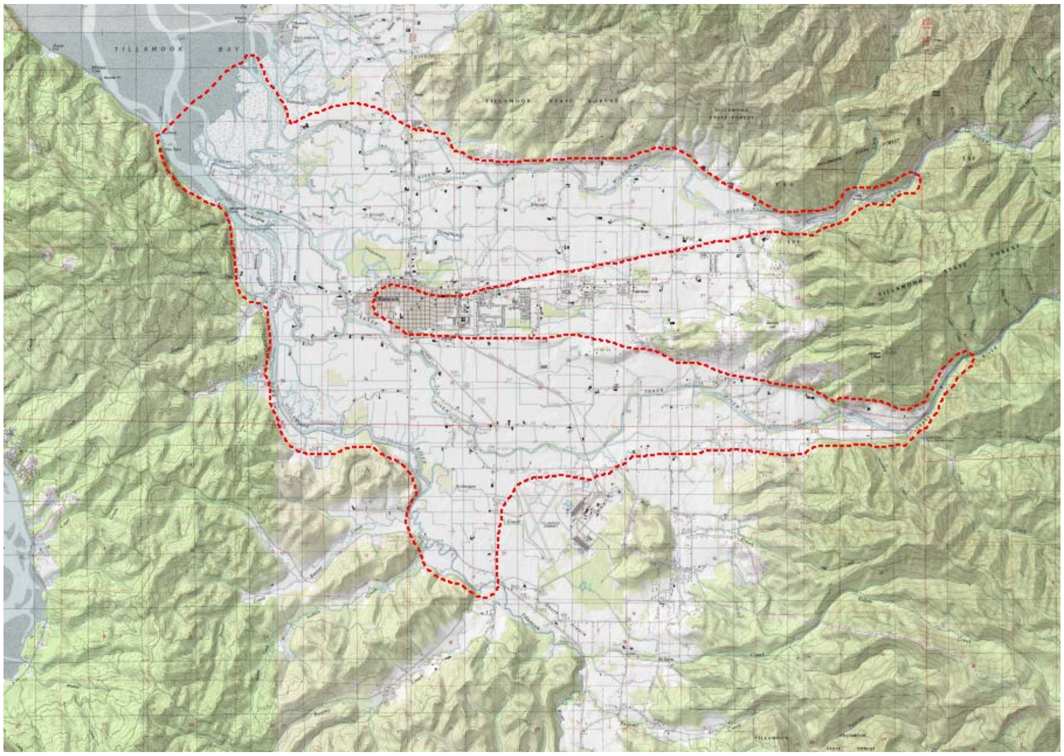


*Figure 11. Area Encompassing the Miami River MIKE11 Model (shown by dashed line)*

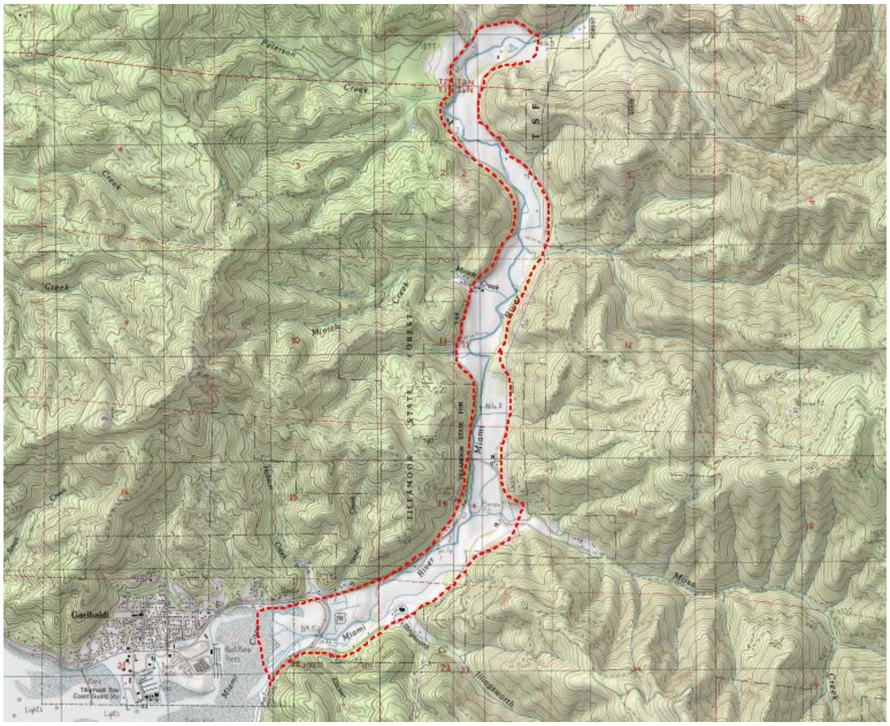
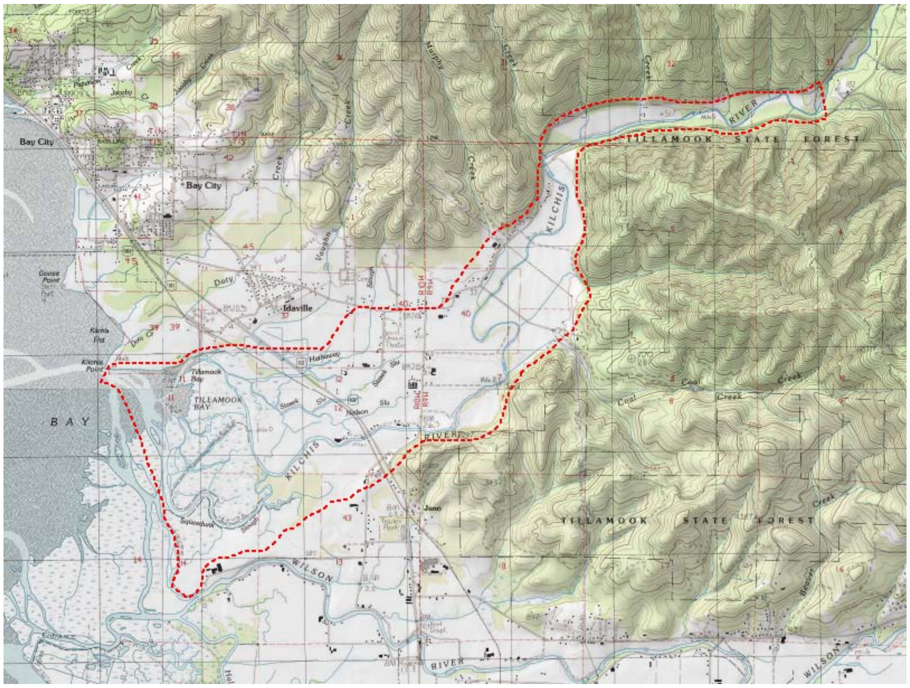


*Figure 12. Area Encompassing the Kilchis River MIKE11 Model (shown by dashed line)*




## Alternative Analysis with the MIKE11 Model

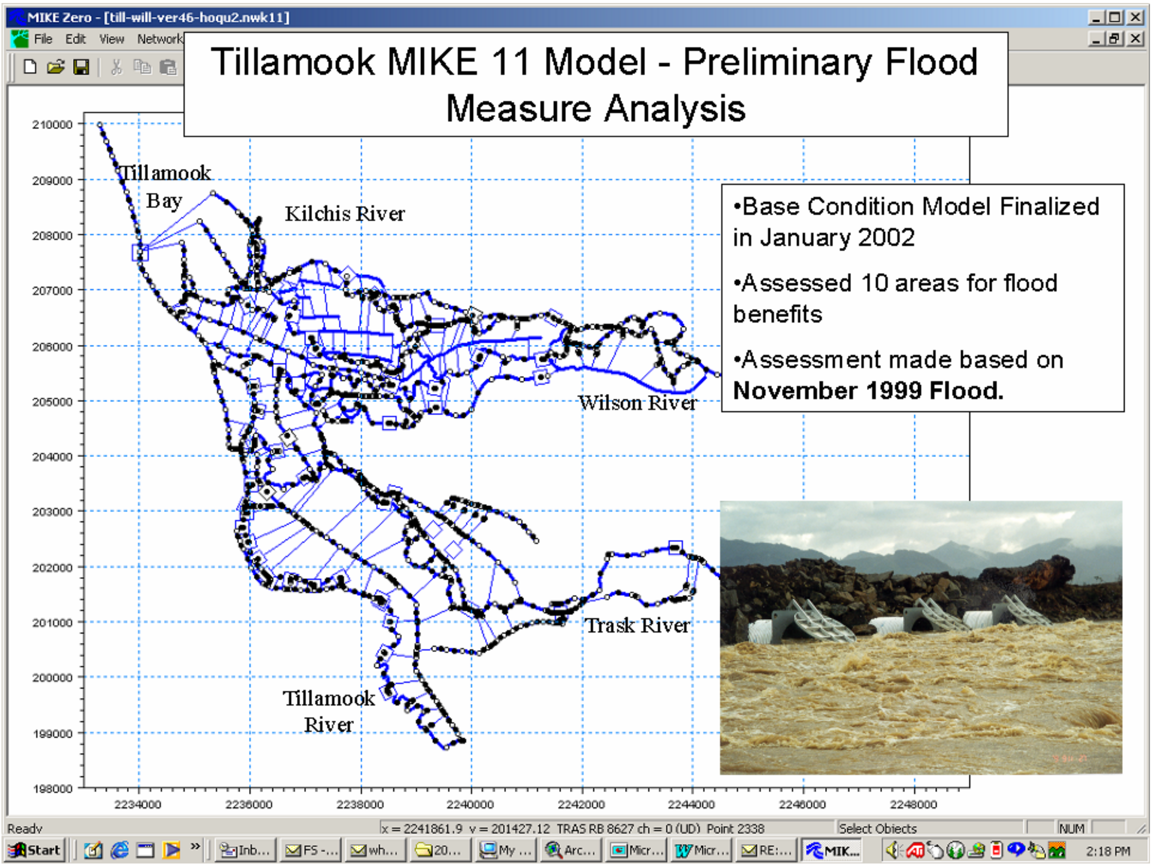
### *Overview of Alternative Analysis*

Alternatives were formulated during final base condition model construction in the winter 2001-2002. Alternatives were formulated by focus groups composed of staff from the Corps, Tillamook County, regulatory agencies, and local citizens. Alternatives were based on the four objectives of the study: reduced in flooding, reduced sedimentation, improved water quality, and improved salmonid habitat. Fifty-nine preliminary alternatives were recommended by the group. At the request of the county, alternatives without flood reduction benefits would not studied further. Therefore, as a first task, each alternative was screened to see if it had any potential flood reduction benefits. If not, then the alternative was dropped from further consideration.

This initial screening left 33 alternatives for further study. At this time, it was determined that with the remaining budget, only alternatives with potential to both resolve the sponsor’s immediate concerns of flood reduction along with ecosystem restoration benefits would be studied in detail. The reasoning for this decision was based on budgetary and time constraints along with the inherent desire of the local community to improve flood conditions. Therefore, the remaining 33 alternatives were evaluated based on engineering and biological judgment for their significance. It was determined by the sponsor that the area of focus should be in and around the City of Tillamook, thereby the alternatives on the Miami and Kilchis Rivers were tabled with the exception of evaluating the lower Kilchis River. This left approximately 14 alternatives to be modeled with MIKE11 (Figure 13). The alternatives were modeled under several configurations and combined with other alternatives to evaluate their response to flooding. Thus, there were many model runs made to evaluate each area and its response to flood conditions. Of these alternatives, it was determined that six alternatives areas provided flood reduction on a scale that met the sponsor’s requirements. These six alternatives were further evaluated.

Discussion of each alternative followed between the local citizens, the sponsor, resource agencies, and the Corps. From these discussions, three alternatives remained for design to determine costs and benefits. Other alternatives were not evaluated further based on environmental concerns, little to no flood reduction benefits, high costs, or a lack of local support.

*Figure 13. MIKE11 Schematic from the MIKE11 Base Condition Model of the Wilson, Trask and Tillamook Rivers*




## *City of Tillamook Area Flood Conditions*

An evaluation of flooding problems around the City of Tillamook was performed by the Corps in order to define alternatives that could possibly alleviate flooding in the area. In order to understand the flooding, an evaluation of the topography was performed. Figure 14 shows the topography of the lower Wilson, Trask and Tillamook Rivers near Tillamook. As shown in Figure 14, the rivers of Tillamook are perched above their floodplains. Their high sediment loads spill out during flood events and are deposited near their banks. The floodplains are lower and are reconnected to the river system through a network of sloughs. However, for agricultural use, the floodplains have been diked along their rivers and sloughs to not allow for tidal inundation. Therefore, when floodwater exits the Wilson, Trask, Kilchis and Tillamook Rivers, it is trapped in the floodplains behind the natural and constructed tidal dikes. A network of 'flood cells' was delineated in lower Tillamook area, which gave the modeling team a way to identify and compare floodplain areas during modeling (Figure 15). Flood cells were delineated based on their independence of one another in flooding condition. Each flood cell acts independently because it is diked from its neighboring flood cell, slough, or river.

*Figure 14. Lower Tillamook Area Topography, Color Coded by Elevation.*

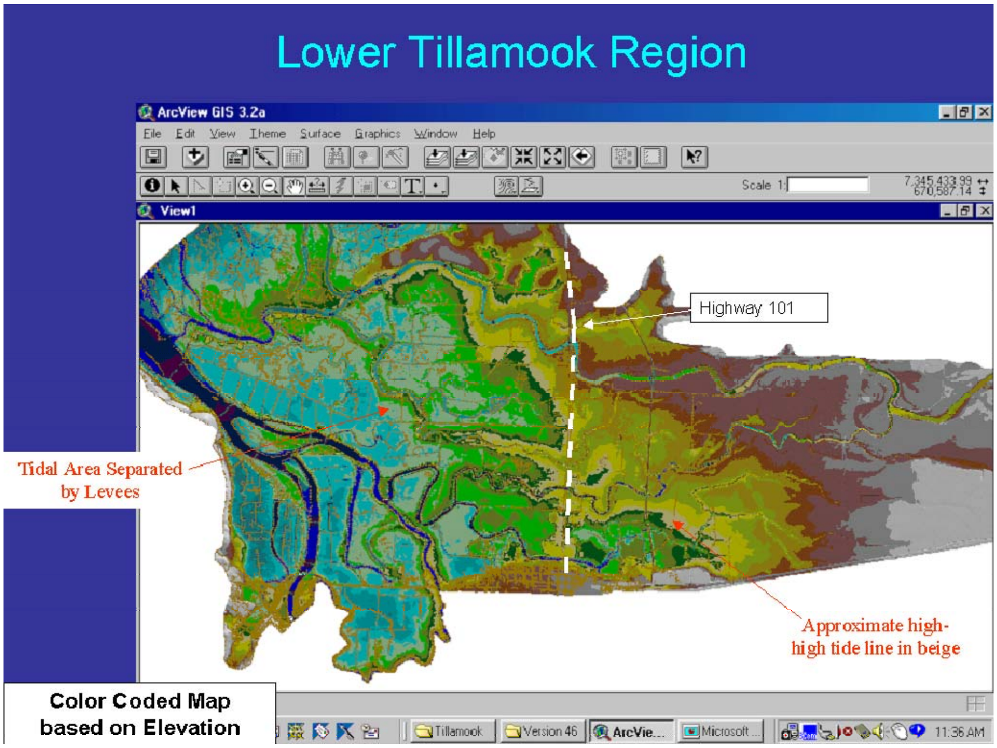
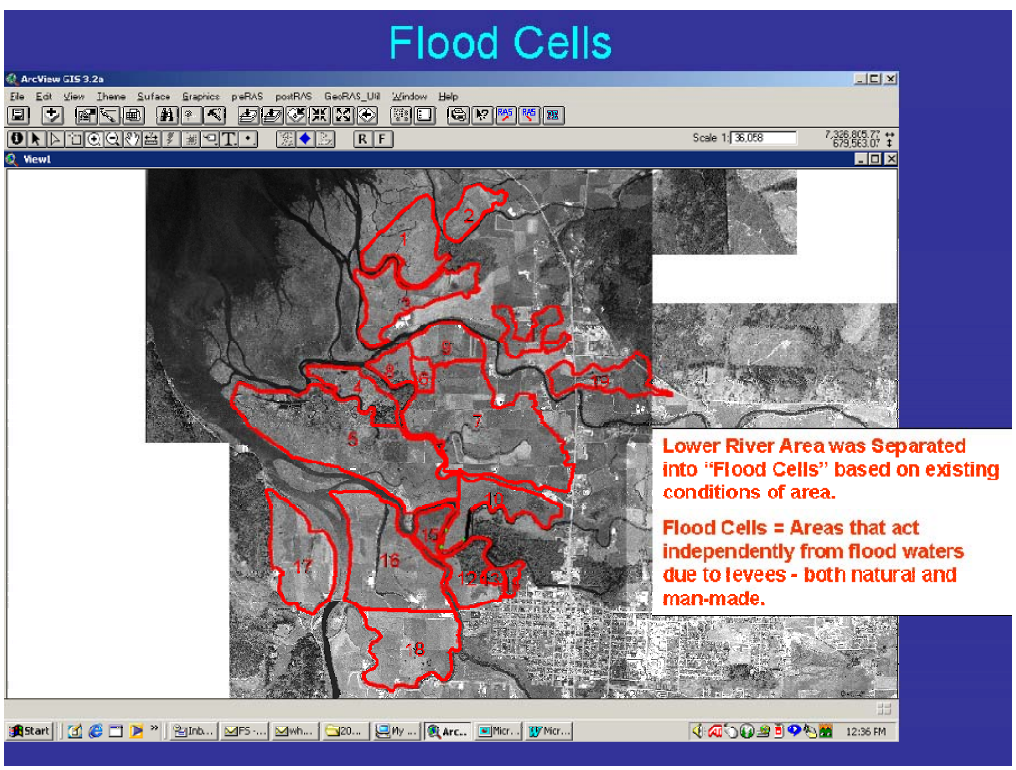



*Figure 15. Flood Cells in the Lower Tillamook Region*



Both natural and constructed dikes have separated the rivers and sloughs of Tillamook from their floodplains. The complex nature of flooding in the Tillamook region has not been analyzed in floodplain development including the placement of tidal dikes. The result is a system of channels that are disconnected and create increased flood problems, including standing water when floods recede, and increased flood stages within channels. Man-made features such as levees, dikes and roads, along with land use practices may have caused flooding in areas that did not historically flood. The rivers have been forced to evacuate all floodwater; however, they will never have the capacity to do so. In analyzing the peak flows from gauges in the region for the November 1999 flood event, it was apparent that the lower rivers do not have the capacity to carry the floodwater, and depend largely upon the floodplain to carry the floodwater to the bay. Table 9 lists the peak discharge of each river and its capacity through its downstream reach to the bay as determined by MIKE11 for the base condition model (November 1999 flood event).

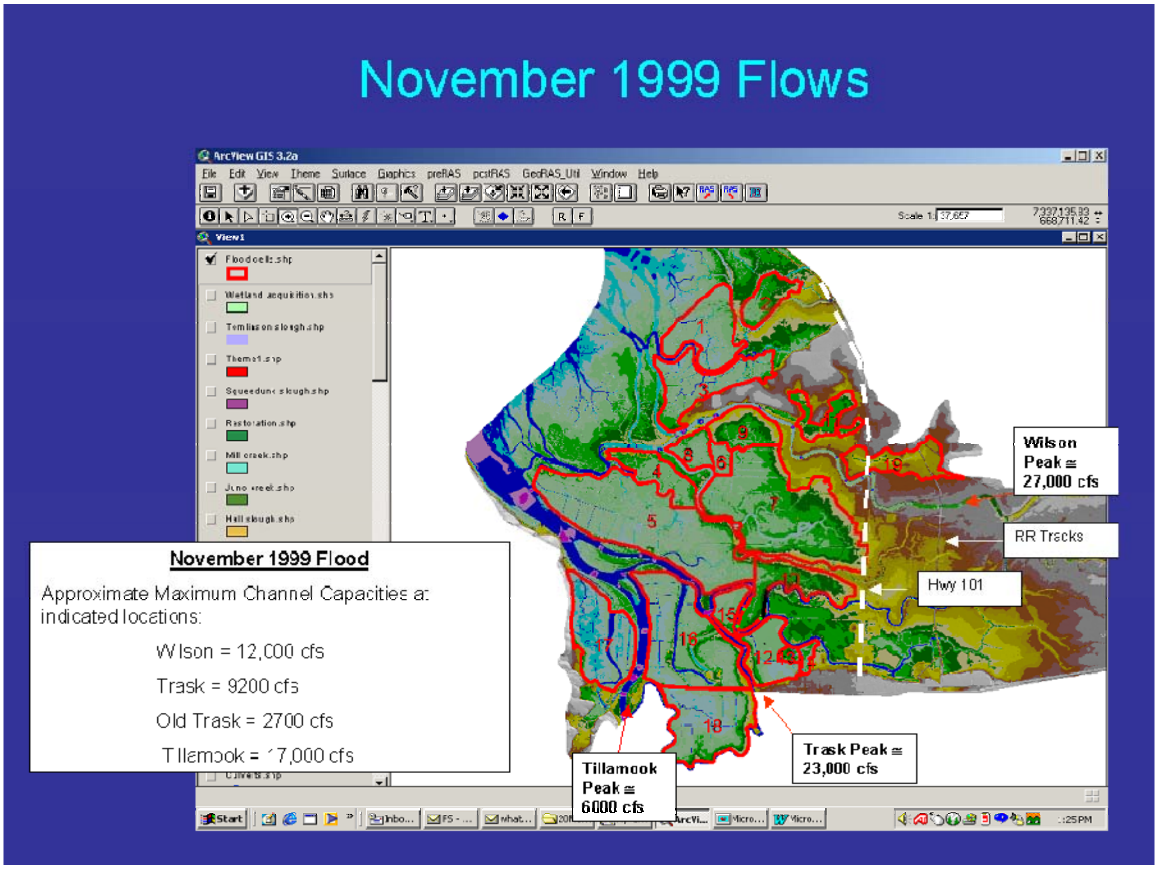
*Table 9. November 1999 Flood Flows for Tillamook Area Rivers as Compared to Channel Capacity*

| River | November 1999 Peak Flow | MIKE11 Peak Channel Capacity at Downstream Reach | Difference |
|---|---|---|---|
| Wilson River | 27,000 cfs (approx. 10-yr. peak) | 12,000 cfs | -15,000 cfs |
| Trask River | 23,000 cfs (approx. 20-yr. peak) | 9,200 cfs | -13,800 cfs |
| Tillamook River | 6,000 cfs (approx. 5-yr. peak) | 17,000 cfs | +11,000 cfs |

As shown in Figure 16, the lower Wilson and Trask Rivers do not have the capacity to move their floodwaters to Tillamook Bay. The Wilson River has approximately 12,000 cfs capacity and the Trask combined with the ‘Old Trask’ has approximately 11,900 cfs capacity. It is natural for rivers to not have the capacity to take flood flows within their banks. Their bankfull discharge (or channel forming discharge) is that discharge that the river can move before it overflows its banks. The bankfull discharge of a river is typically on the order of an annual or bi-annual event. For the Wilson River, 12,000 cfs capacity represents approximately the 90% chance of exceedance flow for any given year. For the Trask River, 11,900 cfs capacity represents approximately the 60% chance of exceedance flow for any given year.

However, the Tillamook River is an anomaly among the three rivers because its lower reach is broad in comparison to its flow, and it has more capacity than the river typically flows. The reason for this is that the Trask River flows towards and into the Tillamook River through floodplains and the Old Trask River adding large amounts of floodwater to the Tillamook River near its mouth. From this evaluation, a reasonable approach to managing Tillamook’s floodwater would be to increase channel capacity at the lower reaches of the Trask and Wilson Rivers, and to reconnect the floodplains in the area. This was analyzed in the alternatives as discussed in the following section.

*Figure 16. November 1999 Flood Flows of Tillamook Area Rivers*




## PRELIMINARY MIKE11 MODELING OF ALTERNATIVES

Preliminary modeling of alternative areas took place to evaluate each area's effectiveness for reducing flood impacts in Tillamook County (Figure 17). Preliminary alternatives were minimally designed and were initially modeled with trapezoidal channel cuts and large channel changes to analyze the area's effectiveness in providing flood reduction benefits. The alternatives were modeled using MIKE11 with the November 1999 flood, and model results were compared to base condition results. After running several scenarios in each alternative area, results were summarized and discussed with the Feasibility Advisory Council. This section discusses each of the initial alternatives evaluated and the MIKE11 modeling results.